# Embedding technology in the structures thread of a civil engineering degree

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## Introduction

This paper describes an ongoing journey, which began in the autumn semester of 2005 and continues to the present day, with the aims of promoting good teaching at the University of Salford, UK. It discusses the challenges faced during the redesign of a civil engineering degree programme and how these techniques have transformed it into an award winning teaching environment. Specifically, the teaching of structural engineering is addressed, tracking the development from common modules shared between three engineering disciplines, through to the integration of practicing structural engineers and the positive impact this had on the students and their understanding of structural behaviour.

## The starting point

In 2005 the teaching of structural engineering at the University of Salford was at something of a low ebb due to staff cuts and reorganisation of facilities, culminating in a situation where mixed discipline (Aeronautical/Civil/Mechanical) first year students were taught structural analysis by non-civil engineering lecturers. This resulted in problems in the understanding and application of fundamental engineering theory which manifested during second and third year modules, often necessitating re-teaching of key concepts to enable progression. The need for change was partly fuelled by the long standing criticism of graduates' ability to apply their knowledge

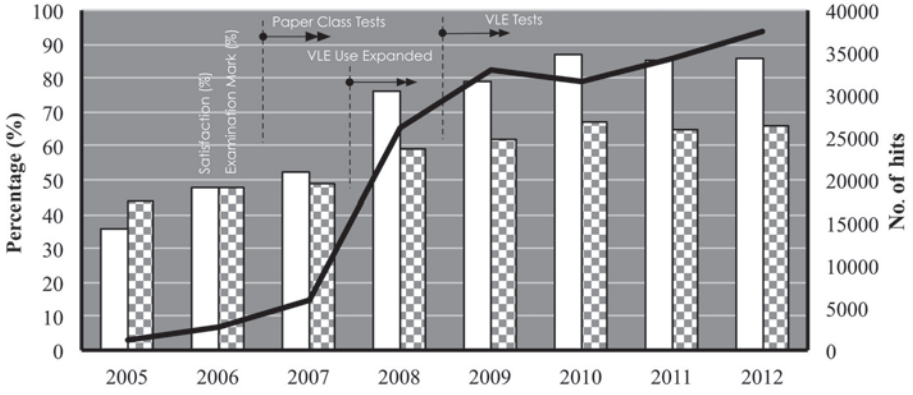



Figure 1
**Progression of first year cohort structures exam mark, satisfaction and VLE use with time**

and solve common structural engineering problems encountered whilst in industry, both in the UK[1-3] and internationally[4].

In the UK, civil engineering taught programmes are accredited by the Joint Board of Moderators (JBM), which represents four civil engineering institutions. JBM is represented equally by industrial and academic engineers, their role being to review output from degree programmes on a periodic basis to ensure academic standards, learning facilities and curriculum design are acceptable, which is the first key step towards obtaining professional status. This is in addition to the role of external examiners. The body that controls registration of professional engineers in the UK is the Engineering Council (EngC). Registration as a Chartered Engineer (CEng) or Incorporated Engineer (IEng) is via an engineering institution and requires satisfactory academic and industrial assessments. A wide range of curriculum and policy documents are available from JBM and EngC, the majority of which deal with embedding non-technical skills into a modern curriculum and promoting 'Good Teaching'[5].

## A process of change

The catalyst for what eventually became a complete restructure of the civil engineering programmes and approach to teaching

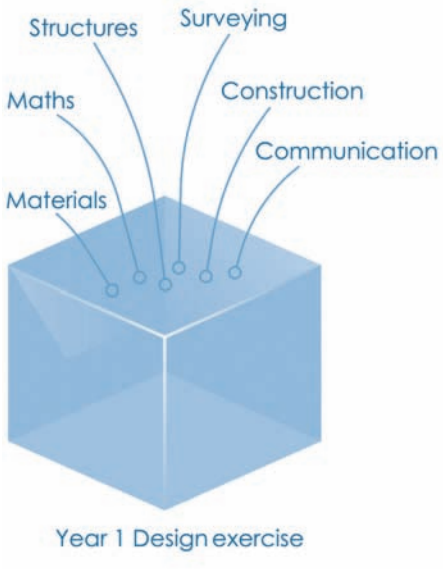



Figure 2
**Putting design at the core of the programme**

within the department, was the expansion of the team through the recruitment of a new civil engineering lecturer, who brought 20 years of industrial experience as a chartered civil and structural engineer. All first year engineering students were originally taught structural engineering in a common group, combining aeronautical, civil and mechanical engineers. A decision was made to embed the experience of a chartered structural engineer into the classroom to test alternative teaching methods, then detach

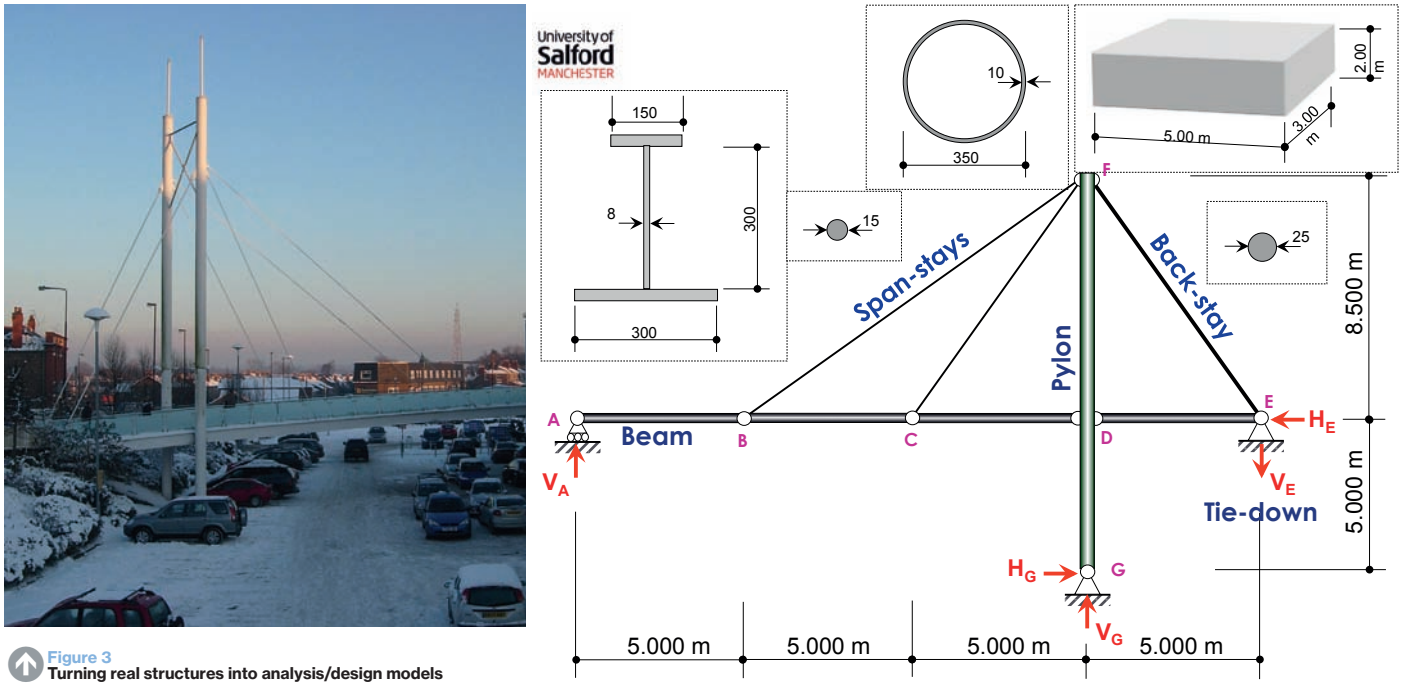



Figure 3
**Turning real structures into analysis/design models**

the civil engineering students from the common stream.

With the exception of syllabus, wholesale changes were made to lecture material, lecture and tutorial style, expectation of output and laboratory arrangements. Use of the university's virtual learning environment (VLE) was also introduced. This has recently led to a more holistic approach to learning across the civil engineering programmes.

Although the effect on workload was detrimental to the lecturing staff, the civil engineering students were taught structures separately from 2007-08. This permitted specific civil engineering topics and examples to be introduced, which resulted in an improved self-perception (identity) of civil engineering students generally, within a broad discipline academic school structure.

As so many changes were introduced in one condensed period it is difficult to identify specific contributors to the improvements in performance but the underlying trends were:

- grossly improved student satisfaction of the structures thread as the student cohort progressed through the programme
- improved quality of output, such as laboratory reports, understanding of structural behaviour, and design

Figure 1 depicts the rise of student satisfaction scores and final examination performance over an eight year period. This is positively related to the general increase in VLE use by students and the coincidental expansion of VLE use and separation of the engineering discipline groups after the 2006-07 academic year.

## Importance of industrial experience

As with most universities, at Salford the aim of teaching structures is to build a student's ability and confidence, and ultimately engender an understanding of structural behaviour in the outgoing graduate. Unlike most universities, our structural engineering staff (including Professors) have spent large proportions of their career in industry (over half a century in total). Interestingly, when the Higher Education Academy (HEA) have held essay competitions for students to identify 'What makes a good engineering lecturer?'[6] on both occasions, the highest response has been 'uses real-world engineering examples backed up by industrial experience'. Our teaching staff are able to demonstrate this through the inclusion of the buildings and bridges they have designed whilst in industry, to use as practical examples and case studies.

With industry relevance and 'practical application of technical skills'[7] in mind, staff set about a redesign of the entire structures syllabus to embrace 'experience led teaching'[8] and in so doing, identified the following as key themes:

- consciously move away from the traditional separation of structural analysis and structural design. This has led to a cross module design exercise which forms 20-30% of the assessment in each year (Figure 2)
- accept the endemic use of computer software in industry but incorporate validation as a necessary skill
- embrace methods of learning adopted by modern students
- integration of real buildings that the staff have worked on to illustrate engineering principles, behaviour, sustainability and good design practice
- promote analogical thinking in the classroom and in group discussions

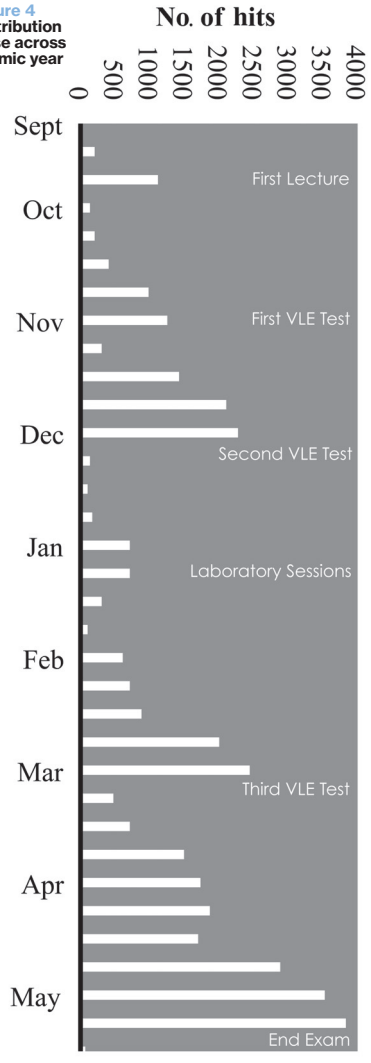
We have actively engaged with key groups through re-establishment of a civil engineering specific Industrial Advisory Board, forging links with local industrial partners, and professional bodies[9]. The design projects set for our students are now realistic, relevant, and exciting. While first year structures must rely heavily upon learning techniques for later development, by the end of semester 2 a student will be expected to analyse and design check a simple cable stayed bridge (Figure 3). This exercise allows students to see the process of design development by effectively working backwards from a real structure to an analysis model, embedding the five key stages of the modelling process[10]. This process is then reinforced when students undertake their semester 1 conceptual design for a small structure and generate and verify a simple analysis model[11], developing and applying their expertise into a realistic structural environment[12].

## Delivery

Salford offers a wide range of IEng and CEng qualifications across a narrow band of civil engineering titles. Structures is a topic in all but the postgraduate Transport MSc and for this reason we must address a wide range of student ability.

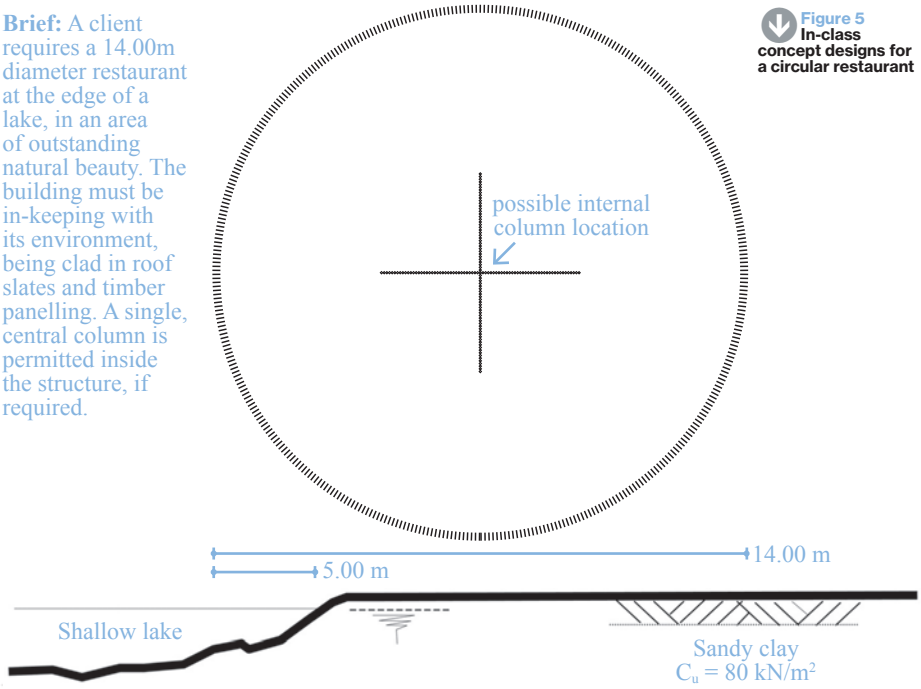
The traditional lecture is a rarity, being replaced by the lectorial - a short statement of principles followed by worked examples and audience participation, which has been found to solicit the best results from most Salford students (the show, don't tell principle). The application of these principles can either be as part of a traditional tutorial based process, or more commonly through the integration of the topic into a larger design project in line with best practice[13]. This process is perhaps most convincing for students because they are often being shown a structure which was designed or constructed by the lecturer, who can explain both why a particular design was developed and elaborate on designs which were rejected. This helps create a 'professionally relevant syllabus'[14]. In addition, a student from any level may ask any structures lecturer a question - as we operate an open-door policy such that capable students thrive and struggling students are assisted.

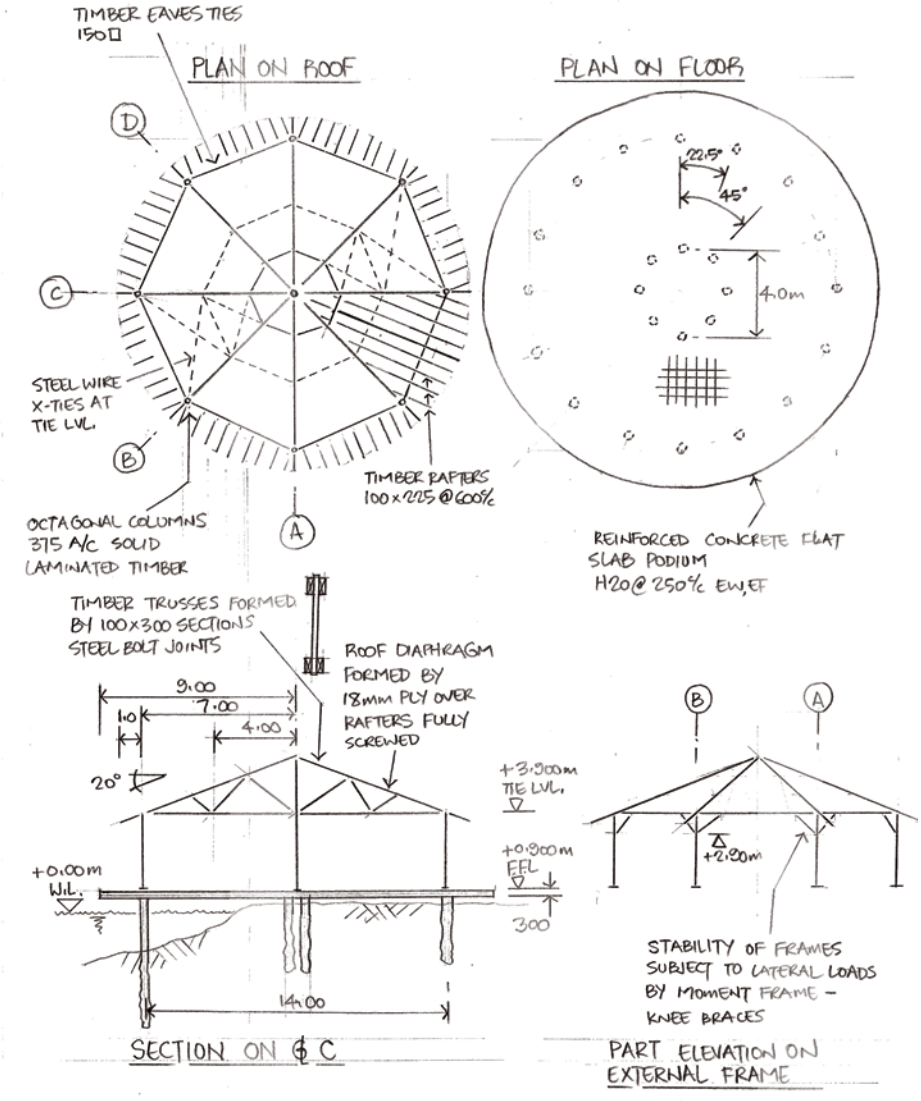
Figure 4 **Distribution of VLE use across an academic year (2011-12)**

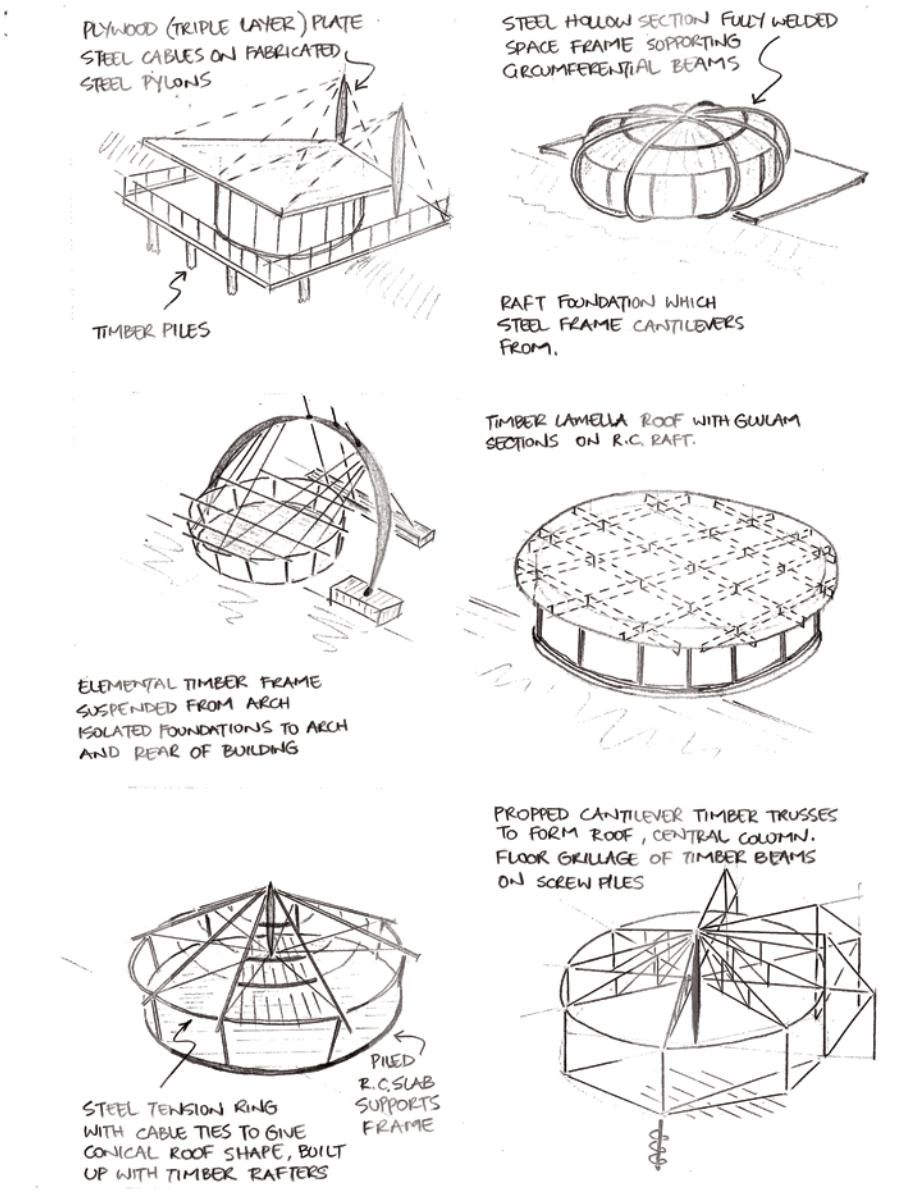



**Brief:** A client requires a 14.00m diameter restaurant at the edge of a lake, in an area of outstanding natural beauty. The building must be in-keeping with its environment, being clad in roof slates and timber panelling. A single, central column is permitted inside the structure, if required.

Figure 5 **In-class concept designs for a circular restaurant**






## Embracing technology

It is desirable to close the gap between student expectation of their performance and reality before first year summer examinations arrive. A series of short, graded VLE based tests have been incorporated into each level, the object being to engender participation in learning (although usually summative to ensure the students focused attention). Students who under-perform are offered an opportunity for additional small group tuition on specific topics following each VLE test. This has proved to be particularly popular and in many cases pivotal to progression.

The enthusiasm with which the VLE exercises have been met is staggering. Students are clearly excited about working online, at any time of the day (or night). The fact that they can be listening to music or even watching TV whilst they undertake the exercises seems to add to their enthusiasm. Results are posted immediately, so feedback is obtained within seconds. Figure 4 reflects the fact that VLE use is strongly tied to preparation for assessment and as such has become the information hub for each module.

Since the introduction of these methods, attendance at tutorials has improved markedly – particularly amongst the students who need to attend to improve performance. This perhaps feels counterintuitive to some of the perceptions held by academics, as many believe that students are likely to abandon timetabled lectures if they can access all learning materials and lectures from the VLE.

Experience has shown that first year students will over-mark their submissions by around 30%. This will reduce by about 10% per year, such that fourth year MEng students are reasonably accurate in guessing their marks. Improvement in this ability is largely due to the quality of feedback provided (and accepted). Feedback is traditionally perceived as being provided by lecturers to students, after assessments are complete, but some of the most effective "wake-up-calls" have been delivered by a carefully selected member of the preceding cohort, who is willing to share their memory of missing a first class mark by 1%.

When a first year design exercise was introduced (contributing to the assessment of all year 1 modules) a series of feedback points (strictly 'feedforwards') were identified throughout the year to improve expectation of quality, content and value by the student. Industrialists will recognise this as a Design Appraisal, but for many students it is their first experience of critique and can be a stressful process. Students are expected to deal with more than just quantitative structures, by addressing questions such as:

- what are the options for structural form?
- what is the most appropriate material for each part?
- where do the forces go?
- how could the structure be improved?
- what is the construction sequence, and can it be safely built?
- are there built-in durability problems?

This is of course, tantamount to incorporating sustainability and safety into the structures curriculum by stealth but is much more likely to become part of the student's subconscious design process if not labelled as such.

Although the structures syllabus is unlikely to change for many years, the style of teaching, methods of assessment and general output are subject to constant review and redress. This is in part due to the requirement for all new lecturers to pass the university's postgraduate Academic Practice course, which is designed to enhance teaching and learning methods. Characteristically, civil engineers have bucked the trend amongst lecturers and grasped the opportunity to implement measured change in teaching, such that designing and testing learning interventions has become a subconscious activity.

One of the most effective ways to ensure students understand is to ask them to give a lecture on the topic[15]. The formative presentation, whether individually or in groups, has a surprising number of benefits including better retention of information (students concentrate for longer when listening to each other) and increased participation in discussion (students are more willing to disagree with each other than

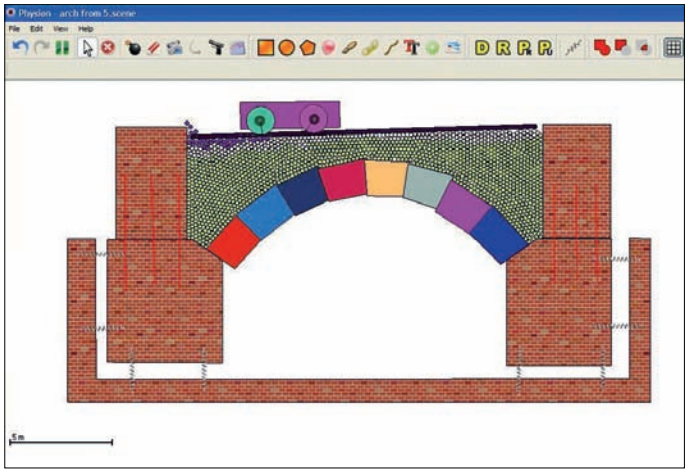


Figure 6
**Physion model of a segmental masonry arch with granular backfill**

Figure 7
**Constructionarium project from 2010-11 (Ravenspurn oil platform)**

with lecturers). Students grow accustomed to shared learning methods with time - first years are often shocked to be asked to engage in formative learning which does not attract credit, whilst third and fourth years can be easily convinced to prepare a ten minute presentation. With careful guidance the formative presentation can be used to explore and evaluate conceptual design options and develop the ability to communicate structural intent (Figure 5). A relatively small group of students (and a visualiser) is best for such intensive activity.

Since seeing really is believing, laboratory experimentation remains at the heart of understanding structural behaviour. As well as the usual academic experimental apparatus, the Heavy Structures Laboratory permits physical testing of almost anything that will fit onto a 20m square strong floor, or onto a 1.5m shaker table. These facilities are used by all levels of the programmes, with most final year Bachelors and Masters students being involved in physical testing. A broad range of structural consultancy activity also contributes to student opportunities to be involved with a real research and development problem. For the student of course, this may turn into a career opportunity.

## Technology for learning structural behaviour

The modern student is markedly different to those of twenty years ago, being more technologically fluent, socially relaxed, and making wide use of social media to break down the barriers of time and location. Detrimentally, few have spent their youth playing with Meccano and Lego, so their grasp of the physical world is more tentative. The challenge for civil engineering programmes is therefore to fill a changing gap by designing programmes that play to students' technological strengths. Now that almost all students are armed with a laptop computer or have the capacity to borrow one from our library, we can expect them to investigate and develop learning with a range of tools. Other than text books and the university VLE, most popular in the structures field are:

- **ActiveStatics** (free MIT qualitative analysis viewer) is a learning environment in its own right. Students can follow the online tutorial questions. Popular because of its highly visual drag-and-drop truss geometry and force polygon systems, making this a playful learning activity
- **LinPro** (a free 2-D static and dynamic stiffness based analysis program) which can be used in conjunction with hand analysis tutorial questions and texts like *Structural Analysis by Example*[16].
- **Physion** (a free real-time physics viewer (Figure 6)) allows students to make working virtual models, enabling the student to see what happens when an element of structure is removed or displaced. It also forms a quick and inexpensive tool to investigate the viability of a final year project experiment. Due to the lively nature of the failure mechanisms, the students find these fun, which improves their participation and motivation, helping to increase their learning[17]
- **SketchUp** (a free 3D modeling suite from Google) is an easy way to see 3D structural arrangements. This also has the capacity to be combined with Sketchy Physics to replicate some of the models created using Physion. For students exploring conceptual design options, SketchUp offers the ultimate show-and-tell tool as walk through visualisations are simple to undertake
- **ANSYS Ed.** (a comprehensive general FEA package, free to students in a limited form) requires intensive tuition but forms the backbone of year 3 and 4 student project analysis output, permitting advanced investigation of impact, tensegrity, composites, masonry and much more.

Since the introduction of the group based design exercise, it has become necessary to improve the electronic communication methods which students use for collaborative learning, with the aim of engendering better interaction and performance. These include:

**VLE tools -** Wikis offer an opportunity for students to write their own text, typically a short paper, which can be peer assessed as part of the learning process
**Web posters -** Used as part of the assessment for dissertations, students create a web page for their literature review
**Reflective blogs -** Through the introduction of blogs, the students are encouraged to reflect on their learning and their designs, promoting deeper understanding of their learning[18]
**GoogleDrive -** A web based document system which permits truly collaborative working for groups (multiple concurrent editing of a single document)
**Peer assessment -** Traditionally a paper based system introduced in the 1990s, electronic peer assessment is used in the assessment of all group based activities. This has the advantage of permitting students to reflect upon the contribution they, and others, have made to the success of the group. Weekly observation of the group and moderation of peer assessment outcome by lecturers is occasionally required if group dynamics deteriorate
**DropBox -** A web storage system which can be used to share data and documents, and provides a safety net for students who inadvertently use the delete key

## Practical skills

Of course, students need a wide range of skills to be successful in industry, although it is tempting to fill civil engineering programmes with structures, we must address all of the accrediting bodies' requirements in each

programme. At Salford, we address the need for a residential field course by challenging all students to successfully complete a project at 'Constructionarium', at the end of year 2 (Figure 7). Constructionarium is an industry sponsored scheme which allows students to do (almost) everything a contractor does - team working, plan a construction sequence, manage risk, design safe systems of work, costing, contracts, construct a piece of civil engineering infrastructure and review success. Once again, understanding structural behaviour is at the heart of such activity as the students must grapple, for the first time, with concepts like false work design and temporary stability. The exposure to this real world environment, plus the level of planning that the students undertake before embarking, helps to make the process memorable and create a firm mental anchor[19] as part of their learning experience.

Providing the opportunity to engage in such an activity is costly in terms of both time and money, but the easiest way to convince students and university administrators alike, is the extremely positive testimony from students who have just completed the event. We have been so impressed by the students reaction to this all inclusive holiday we made a promotional film which can be found on YouTube[20].

## Conclusion

Reclaiming the teaching of civil engineering first year students, and using a broad range of experienced engineers who are willing to instigate and implement change has not only embraced the marks of excellence identified by the HEA[21] and JBM but has also encouraged the development of a civil engineering community within the school.

The net result is a more holistic approach to student learning which promotes independent thought and an investigative style of working. It can be easy to simply recycle lecture notes year after year and to coast through a career as a lecturer if the opportunity to revel in change is not embraced. Structural engineering lecturers are therefore lucky that the discipline is subject to constant and unavoidable change, providing opportunities for both proactive and reactive alterations to the learning experience.

The adoption of technology in many guises has helped to improve both student satisfaction and the general understanding of structural behaviour, particularly when contained within a practical design exercise.

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